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The sesquicentennial of palaeomagnetism and rock magnetism in Australia

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Beginning with some extraordinary observations made by Strzelecki in 1845, a brief history of the development of palaeomagnetism and rock magnetism in Australia is presented. Through a number of factors, ranging from prescient leadership to Australia's special geography and unique geological past, Australia's contribution to these fields surpasses what might otherwise be expected. Although this was particularly so in the early days, it continues to be so today. Australian palaeomagnetic and rock magnetic research currently leads the world in both applied areas, such as mineral exploration, and in fundamental areas, such as geodynamo mechanisms. Australia's high profile in IAGA Palaeomagnetism and Rock Magnetism database development can be traced back to the natural advantage bestowed by the dedication of Irving, and later McElhinny, at ANU in their frequent publication of the Geophysical Journal of the Royal Astronomical Society pole lists. The major Australian laboratories and the contributions that they have made are outlined.

Introduction

> Its colour in the recent fracture is blackish green; on the surface, yellowish brown. The lustre of the paste waxy; that of the hornblende which it contains vitreous; it does not adhere to the tongue, and exhales an argillaceous odour; its streak is dissimilar and dull; its colour a brownish grey; when struck with a hammer, it gives a metallic sound: it is compact, hard, its fracture is somewhat concoidal. The structure is prismatic, the prisms having three, four, five, six, or seven sides. Their diameter varies from three to eight feet; the length of two or three columns, which are still entire, exceeds 100 feet. The clustered columns are sometimes very closely united; sometimes they are only in close contact, and are separated by the fall of the masses. Some of the columns have but a slight influence upon the magnetic needle; and in these the axes range east and west. The columns lying parallel with the meridian, or nearly so, disclose a strong polarity; a phenomenon worth noting, as the property seems to be more dependent on the bearing of the axes of these columns than on their constituents. The discovery of this polarity was consequent upon the anomalous results which the observations of the magnetic intensity furnished me by the prismatic greenstone on Ben Lomond (*Strzelecki 1845 p. 104*).

The above account given by Paul Strzelecki in 1845 is probably the earliest reference to rock magnetism in Australian literature. The 'greenstone' on Ben Lomond he refers to is clearly the Tasmanian Dolerite. Strzelecki recognised and described the dependence of magnetic effects on the orientation of fallen columns. These observations were not simply mundane compass deflections. It would appear that Strzelecki measured the total field anomalies of a number of columns while taking routine magnetic intensity measurements. Indeed, had Strzelecki been distracted further by his curious observations, and had he the fortune of understanding contemporary developments in the research of electromagnetic phenomena, he would have concluded that the Tasmanian Dolerites were magnetised in a steep-upward direction. Of course he would then have deduced that Tasmania was near the magnetic south pole when these rocks formed and wondered if the pole came to Australia or Australia to the pole. By themselves, his observations would not have been enough to differentiate between the two possibilities now known as polar wander and continental drift. Clarification of this momentous question required another century or so and observations from rocks from other continents.

Quite apart from the above, the Tasmanian Dolerite has played a central role in the development of palaeomagnetism, not just in Australia but globally. Another Australian rock formation that has become enshrined in palaeomagnetic history is the Gerringong Volcanics, on the Illawarra coast, NSW, previously known as the Upper Marine Latites. An oriented sample from the Blowhole Flow at Kiama had been collected in the 1920s by Dr W.R. Browne, University of Sydney, and sent to P.L. Mercanton in France. Mercanton's interest was magnetic polarity, and it transpired that these Kiaman rocks were reversely polarised, the first Palaeozoic rocks to be found with this polarity (Mercanton 1926). This is discussed further below.

This paper is a personal perspective on Australian palaeomagnetic and rock magnetic studies. A brief history is given, with an emphasis on the important role these studies have played in the early days. It is difficult today to appreciate the courage that early palaeomagnetic studies took, with almost no-one believing in their interpretation and implications. I have concentrated on contributions of the main laboratories, although it is recognised that several universities have acquired basic measurement equipment, and some of these, it is hoped, may develop significant research programs in the future.

Early days

One of the most exciting developments in geophysics must surely have been the emergence of polar wandering from the mire of early palaeomagnetic observations. Irving's (1956a) confirmation of an ancient axial dipole, that is, a palaeomagnetic dipole field co-axial with palaeolatitudinal zonings gave rise to the axial geocentric dipole (AGD) hypothesis that underpins the whole palaeomagnetic edifice. For reasons unknown, this has since become known as the GAD hypothesis.

The debate that followed on polar wander versus continental drift divided the Earth sciences research community, with some of the more open minded authorities changing their views rapidly as new evidence became available. In comparing results from Europe and the USA, Runcorn (1956a) concluded that 'the agreement is sufficiently close to give strong support to the hypothesis of polar wandering', later converting to 'these seem to require about 20° of displacement of America west from Europe in post Triassic times' (Runcorn 1956b). Revisitation of these judgements conveys the sense of uncertainty that must, initially at least, accompany great discoveries.

Ted Irving arrived in Australia in 1954 from Cambridge to take up a research position with Professor John Jaeger at the forerunner of the Research School of Earth Sciences at the Australian National University (ANU) in Canberra. Runcorn probably learnt of Irving's (1956b) work before publication, so it is not surprising that he quickly changed his mind. The difference between the polar wander paths of Europe and North America that Runcorn had been reporting is one of longitude, because these landmasses had apparently moved latitudinally in the same sense, and at about the same rate for the past few hundred million years. On the other hand, Australia has moved in the opposite sense latitudinally compared with

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Europe and North America, and Irving's pole path for Australia shows this dramatically (Fig. 1). The supremacy of continental drift over pure polar wander necessitated the introduction of the new term 'apparent polar wander path' to de-emphasise the earlier interpretation of the mobility being purely that of the magnetic pole.

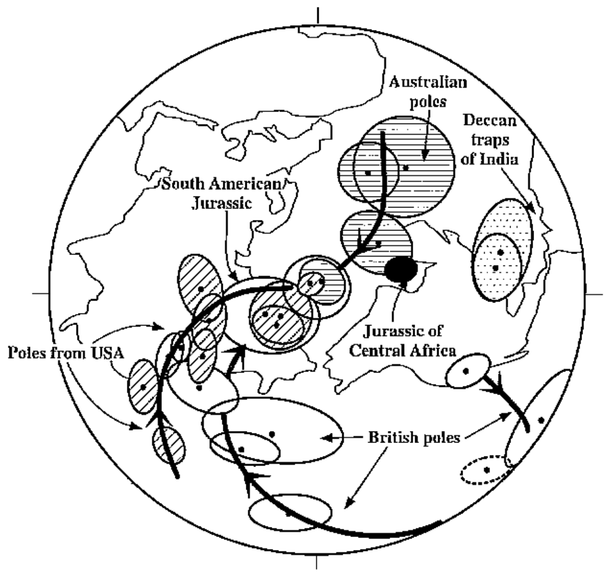

Figure 1. Pole positions relative to the present distribution of continents determined from observations from six continents: Europe, North America, Africa, Australia, Asia and South America (after Jaeger & Irving 1957).

It is ironic that Irving (pers. comm. 1992) originally had not wanted to study the Tasmanian Dolerite because its geological age is only loosely constrained stratigraphically, as indicated in the title of his 1956b paper. Jaeger, however, needed a vehicle in Tasmania for his heat-flow studies, and in any case was interested in the cooling history of the dolerite sills and the secular variation of the geomagnetic field recorded therein. By the early 1960s K-Ar dating fixed the age of the dolerite to a few million years (McDougall 1961). In Irving's own words, 'The old man was right!'. Irving discovered what Strzelecki might have over a century before, that the remanent magnetisation of the Tasmanian Dolerite is directed vertically upward. As an aside to this, Irving tells a marvellous story of his first meeting with Professor Sam Carey, who had agreed to introduce Irving to the dolerites, involving a rope-ladder and a helicopter descending out of the mist that often shrouds the Western Tiers of Tasmania. Irving had become unsettled when Professor Carey's arrival was overdue, initially thinking he has misread his instructions, and was understandably surprised by Carey's mode of transport. Those who knew that Carey was a paratrooper in World War II, and at the time was still an active parachutist, may not have been surprised. Carey was an early and enthusiastic advocate of continental drift and clearly understood the potential that palaeomagnetism held for testing the hypothesis.

One of the first symposia on continental drift was convened by Carey in Hobart in 1956 (Carey 1958), attracting many international notables, some for and some against drift. One of these, Chester Longwell, USA, who wrote the epilogue to the proceedings and initially belonged to the latter group, appears to have been swayed somewhat by the arguments put in favour of drift at the symposium. In his symposium contribution Longwell argued that to explain apparent polar wander 'the most plausible suggestion is that ... the body of the Earth has slowly turned' (Longwell, in Carey 1958, p. 6), this being consistent with true polar wander. However, after assessing the persuasive evidence presented in favour of continental drift by Irving at the symposium (Irving, in Carey 1958, pp. 24–61), Longwell notes in the epilogue that 'readers will see much merit in Irving's analysis' (Longwell, in Carey 1958, p. 357). Again there is evidence of receptive individuals in the scientific community changing their opinions rapidly as the evidence mounted.

Irving and his first student, Ron Green, built Australia's first palaeomagnetic laboratory in the middle of the ANU campus, away from other buildings and magnetic interference, and in a surprisingly short time had an outline of the Australian apparent polar wander path (Irving & Green 1958). While some pole positions have since been shown to be younger than first thought, being results of overprinting, this was a remarkable feat considering cleaning techniques had not been developed. Irving also began regular publications of pole lists (in the Geophysical Journal of the Royal Astronomical Society — GJRAS), precursors to today's Global Palaeomagnetic Database. This database is mentioned further below. Because of demands on space, the laboratory was later moved to its present site on Black Mountain in Canberra, where it is now operated by the Australian Geological Survey Organisation (AGSO). Although involved in the design of the Black Mountain laboratory, Irving departed for Canada before it was completed.

Other students of Irving's in the 1960s were Don Tarling, Bill Robertson and Jim Briden. Tarling and Robertson are mentioned further below, in the context of the early polarity time-scale and the CSIRO laboratory respectively. Briden's emphasis was on pre-Carboniferous (Palaeozoic/Late Precambrian) rocks, mostly from the Lachlan and Adelaide Fold Belts. Briden (1965) was the first to appreciate the complexity of magnetic remanence and the prevalence of magnetic overprinting in multiply deformed rocks. Even today, there are only a handful of reliable results that have been gleaned from this fold belt.

In 1956 Frank Stacey joined the ANU group to study rock magnetism and to put palaeomagnetism on a reliable theoretical basis. A fundamental question to be answered at that time was whether the direction of thermoremanent magnetisation acquired by rocks, which may have been under considerable stress, is deflected significantly when the stress is released (either through denudation or drilling). Systematic magnetostriction experiments carried out by Stott & Stacey (1959) discovered one of those quirks of nature; for intrinsically isotropic rocks the deflection accompanying stress release exactly annuls that caused by the stress in the first place, thus justifying the general assumption made in palaeomagnetism that the measured remanence is parallel to the palaeo-field.

Stacey (1960) was the first to apply high-field torque measurements to magnetostriction and magnetic anisotropy studies of weakly magnetic materials such as rocks. Perhaps of greater currency, Stacey (1961) introduced the term 'pseudo-single domain' for that fraction of magnetic remanence carriers that possess single-domain-like behaviour, but are far too large to be truly single domain. While the real nature of pseudo-single domain particles is still a vexed question, empirically they explain why so many rock types yield reliable palaeomagnetic data.

These studies placed palaeomagnetism on a sound physical basis, adding weight to tectonic interpretations and the validity of continental drift. Stacey returned to the UK (Cambridge) in 1961. There he produced a seminal work on his investigations in Australia and summarised those of other pioneers, such as Louis Néel, laying the foundations of theoretical rock magnetism (Stacey 1963). In 1964 Stacey returned to Australia after being appointed Reader in Physics at the University of Queensland. His interests in rock magnetism had not waned and later he and Subir Banerjee (University of Minnesota) produced the first book devoted to theoretical rock magnetism (Stacey & Banerjee 1974). This contribution, describing the principles of rock magnetism, made the subject more accessible and helped palaeomagnetists in developing techniques to improve the quality and reliability of their work. Rock magnetism is now a mandatory adjunct to palaeomagnetic studies.

One of Irving's last studies in Australia before leaving in 1964 was in collaboration with Lin Parry, a physicist from the University of New South Wales. Parry was the first to carry out a systematic study of the size-dependent magnetic properties of annealed and dispersed magnetite particles, such as occur in rocks (Parry 1965). His observations were central to the theory developed by Stacey. Irving and Parry (1963) were the first to recognise that the geomagnetic field maintained a constant reverse polarity throughout the Late Palaeozoic and suggested the term Kiaman Interval after Mercanton's (1926) study of the sample from Kiama provided by Browne (mentioned above). Although this period is now formally known as the Late Palaeozoic Reverse Superchron, the more romantic term 'Kiaman Interval' prevails. Numerous studies on other continents have since shown their hypothesis to be essentially correct, although pin-pointing the boundaries has proved difficult. With Neil Opdyke (University of Florida) and John Roberts (University of New South Wales), Irving is currently refining the lower boundary of this important time interval by revisiting the sequences in New England (NSW), which are now much better mapped and dated. It was a lucky chance that Browne collected from the Blowhole Flow because it is now known that most seaboard rocks have been heavily overprinted during Cretaceous events before Tasman rifting. The rock magnetism work reported by Irving and Parry (1963) shows that the Blowhole Flow possesses ideal palaeomagnetic recorders that have resisted resetting and possess negligible normal polarity magnetisation from the Cretaceous event. It is somewhat incongruous that the term Kiaman remagnetisation has been popularised, referring to remagnetisation during the reverse Permian period, while remagnetisation at Kiama was actually Cretaceous.

Other important early work carried out at ANU related to palaeomagnetism was that of Ian McDougall, who had established a very productive K–Ar laboratory at ANU capable of measuring ages of very young igneous rocks. McDougall and palaeomagnetist Don Tarling, and later Francois Chamalaun, were among the first to erect a polarity time scale for the past few million years (McDougall & Tarling 1964, McDougall & Chamalaun 1966). From a palaeomagnetic viewpoint, apart from contributing to an early magnetostratigraphic framework, this work was instrumental in dismissing the self-reversal explanation for reverse polarity rocks. Chamalaun also showed that polar wander could be used to date rock-types and mineralising events that were difficult to date any other way (Chamalaun & Porath 1968).

Irving spent 10 years in Australia, putting it on the map palaeomagnetically. His research culminated in the first English text book on palaeomagnetism (Irving 1964), an outstanding contribution that remains eminently readable today. Jaeger had succeeded in establishing ANU as a palaeomagnetic/rock magnetic mecca which was to remain influential for decades.

The Black Mountain laboratory

The cruciform shape of the Black Mountain laboratory, and its precise alignment with the magnetic meridian, would, no doubt, have fascinated Eric Von Daniken. However, it is simply a very practical compromise between maximising the number of Helmholtz coil sets and the distances between them, and minimising the size of the laboratory (Fig. 2). Helmholtz coils are required to control the magnetic field, usually to annul it for astatic magnetometers and alternating field or thermal demagnetisation. The sensitivity of the astatic magnetometer could be made very high by reducing the magnetic gradient, but only at the expense of measurement time. In practice, workers concentrated on the more strongly magnetised rocks (igneous and red-beds), which produced reasonable gradients.

Mike McElhinny arrived in 1967 from Salisbury, Rhodesia (now Harare, Zimbabwe) to take over Irving's role. By then, continental drift was becoming more accepted, largely because the reality of seafloor spreading now seemed unavoidable after publication of the compelling interpretation of oceanic magnetic anomalies (Vine & Matthews 1963). Having undertaken his PhD in ionospheric physics before taking up palaeomagnetism in 1959, McElhinny's interests were less geological than were Irving's, and although much geologically and tectonically related palaeomagnetic work was to continue, this era saw a subtle change in research emphasis. New instruments and computers were becoming available, and while these did not increase sensitivity greatly, they certainly reduced the time and effort required. No longer were readings written down and punched onto cards for a centralised computer to process. Results were immediate, greatly expediting the treatment of samples. McElhinny continued the ANU tradition of producing regular GJRAS pole lists, which became inextricably linked to computer systems as time went by.

Natural diversification led to several new avenues opening up in the 1970s such as archaeomagnetism and investigations of the behaviour of the geomagnetic field, palaeointensity, magnetic transitions, excursions and secular variation studies.

Figure 2. Black Mountain laboratory, Canberra. Its original cruciform shape has been altered by the addition of another wing in 1985.

The 1970s saw palaeomagnetic studies blossom at ANU, and at any one time there were usually 4 or 5 PhD students investigating an array of problems, such as archaeo-intensities as recorded by aboriginal fire-hearths, palaeolatitudes of Precambrian glaciations, palaeosecular variation as recorded in lake sediments, oceanic island chains and hot-spot evolution. In 1973 McElhinny published another text book on palaeomagnetism with an emphasis on its role in the development of the new plate tectonic theory, incorporating both continental drift and seafloor spreading. This book (McElhinny 1973) summarised the state-of-the-art, and was received much more readily than was Irving's book.

The development of the SQUID sensor and its adaptation to rock magnetometers in the late 1970s was a dramatic development, opening up the possibility of studying all lithologies. The speed with which samples could be processed increased so much that a PhD study, which in the 1960s involved 250–300 samples, in the 1980s usually involved thousands of samples. The ability to measure all lithologies coupled with the ability to process thousands of samples allowed the realisation of magnetostratigraphy as a practical method. This technique has been applied to petroleum and gas exploration with great success.

A number of research fellows were attracted to ANU during McElhinny's time: Brian Embleton in 1971, Chris Klootwijk in 1975 and Phil McFadden in 1980. Embleton carried out studies on Palaeozoic rocks in Australia, particularly central Australia, comparing results from southeast Australia with those from 'cratonic' Australia. On the basis of these studies, McElhinny & Embleton (1974) were the first to hint that the Lachlan Fold Belt was composed of allochthonous terranes. McElhinny & Embleton (1976) also settled an old argument about the position of Madagascar in Gondwanaland. Their solution has since been confirmed by the precise mapping of marine magnetic anomalies. Klootwijk, who had studied Indian rocks for his PhD in Utrecht, returned to the Indian subcontinent to undertake a major palaeomagnetic study of the tectonic development of the Himalayan Fold Belt (Klootwijk 1979, 1984). This work was crucial to reconstructing the India-Asia collision and restoring the north-eastern margin of the Indian subcontinent to its former extent before India's collision.

Eminent sabbatical workers were also attracted to ANU during McElhinny's time such as Ron Merrill (University of Washington), David Stone (University of Alaska), Neil Opdyke (University of Florida), Roy Thompson (University of Edinburgh) and Ken Hoffman (California Polytechnic State University). Collaboration between McElhinny and Merrill led to the first attempt to relate palaeomagnetic constraints on the ancient geomagnetic field to dynamo theories (McElhinny & Merrill 1975). Their joint work culminated in the writing of their book (Merrill & McElhinny 1983), the preface of which sets out their aims in relating palaeomagnetism to dynamo theory. Merrill's first visit was in 1974 and he has returned regularly to Australia since then to continue collaboration, initially with McElhinny, but over the last decade, more with McFadden. A series of influential papers have come from the 3Ms, McFadden, Merrill and McElhinny, in various combinations, on the behaviour of the internal field as constrained by palaeomagnetic observations (e.g. McFadden et al. 1988 1991, McFadden & Merrill 1995). A new book by Merrill, McElhinny and McFadden summarising the past decade's collaboration is imminent. In addition to work on the dynamo, McFadden and others (e.g. McFadden 1990; McFadden & Schmidt 1986; McFadden & McElhinny 1990, 1995) have produced a variety of useful statistical tests and methods for palaeomagnetic data.

With McElhinny's departure to the Bureau of Mineral Resources (BMR, now AGSO) in 1982, ANU reassessed its position and after 30 years of world leading research in palaeomagnetism decided that this field was no longer central to its goals. It struck a deal with the BMR to take over the Black Mountain laboratory. This was opportune, since a research component had recently been added to BMR's more traditional role of surveying and database repository. The transfer of palaeomagnetic research from ANU was finally completed when Phil McFadden left to join the BMR in 1983. Although McElhinny resigned in 1988, after a brief few years he found himself transforming the pole lists into a global palaeomagnetic database. Implementing the database was actually much more than simply importing the pole-lists into a suitable software environment, since many more data fields were added. Although instigated by Phil McFadden, development of the database was sponsored by many agencies under the auspices of the International Association of Geomagnetism and Aeronomy, especially the US National Science Foundation, having received strong endorsement from Rob Van der Voo (University of Michigan). With the parallel development of computer hardware and software this database has facilitated palaeomagnetic research beyond expectations and is a superb example of strategic research. Other databases McElhinny has since developed, or is developing (in collaboration with other experts), include SECVR (Secular variation — mainly from lake sediments), PSVRL (Palaeosecular Variation from Lavas), TRANS (Polarity transitions) and MAGST (Magnetostratigraphy). These databases do, or will, provide instant access to a huge amount of data for anyone with modest computer literacy.

Chris Klootwijk, who went to the University of Paris after his time at ANU, and Charles Barton, joined the BMR at this time to stimulate their new research drive. Barton, who was the first to construct a Holocene secular variation chart for the Southern Hemisphere while studying at ANU (Barton & McElhinny 1981), returned to Australia from the University of Rhode Island.

Other important contributions from the AGSO laboratory include Idnurm's (1985) Late Mesozoic to Cenozoic apparent polar wander path and Idnurm & Giddings (1988) Precambrian apparent polar wander path. Their study of the Macarthur Basin sedimentary sequence was a monumental undertaking, foreshadowing the scale of a palaeomagnetic study necessary to disentangle multicomponent magnetisations and extract a complete tectonic/drift history for a major sedimentary basin.

CSIRO North Ryde laboratory

In 1972 the CSIRO established a new Division, based at North Ryde, to assist minerals exploration in Australia. Under the direction of the Chief, Ken McCracken, Bill Robertson set up a palaeomagnetism and rock magnetism laboratory at the North Ryde site in two old farmhouses. As mentioned above, Robertson had studied under Irving at ANU in the 1960s, but had gone to Canada before coming back to Australia to take up this post. Robertson started a number of projects having commercial applications, including studies of iron ore and banded iron formations in Western Australia and intrusions in the Sydney Basin, the latter being sources of industrial aggregate. However, commercial sponsorship of research did not begin in earnest until Embleton took over the laboratory after Robertson resigned in 1977. Embleton, who had worked with McElhinny at ANU from 1971, took up a position with Robertson in 1975. In 1980 a new special purpose laboratory was completed at North Ryde (Fig. 3). Besides offices, this laboratory was designed to accommodate three Helmholtz coil sets, although only two were required since one of the old farmhouses of the original laboratory, which housed the AF demagnetiser, was retained. The other two coil sets provided field control for a cryogenic magnetometer and a computer controlled carousel furnace that automatically heats and cools samples without operator attendance. This furnace has the same sample throughput as the cryogenic magnetometer,

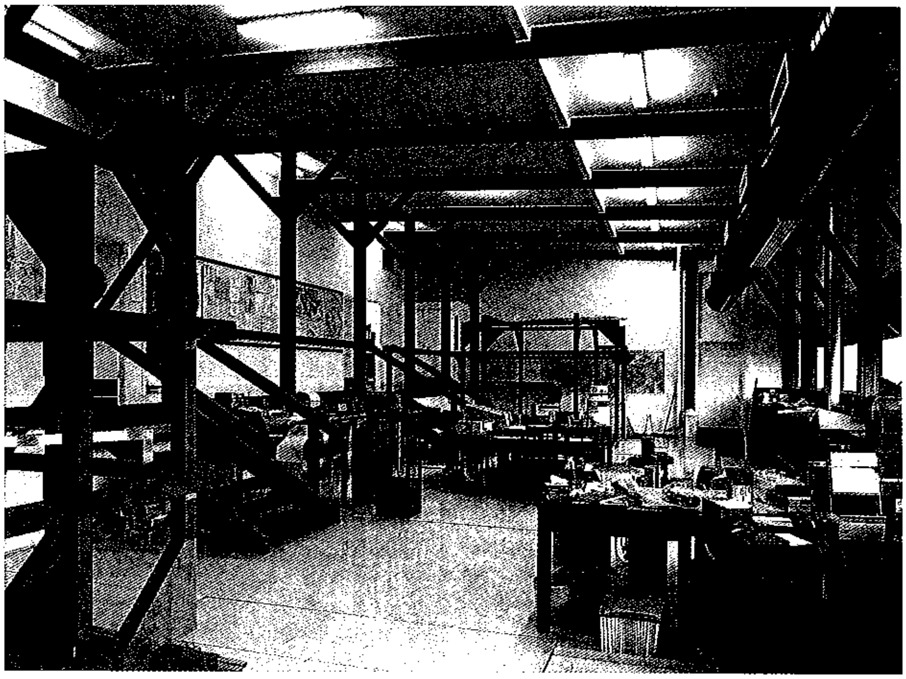

Figure 3. CSIRO North Ryde (Sydney) laboratory, showing Helmholtz coil sets for the cryogenic magnetometer (background) and the furnace (foreground).

optimising efficiency and enabling up to 200 samples to be processed each week.

Extension of the work begun by Robertson in the Sydney Basin led to an important paper showing that significant stratigraphy, probably including Jurassic strata, has been stripped from the Sydney Basin since the Cretaceous (Schmidt & Embleton 1981). Over the years the laboratory has produced many key-poles for the Australian apparent polar wander path. Fundamental contributions from this laboratory include those of Clark & Schmidt (1981), on the thermomagnetic properties of titanomagnetites, Schmidt (1982, 1985) on palaeomagnetic data analysis, and Embleton & Williams (1986) and Schmidt et al. (1991) on the palaeomagnetic evidence for low-latitude glaciations in the Precambrian. Many other contributions are of a more applied nature (Clark 1983, 1984; Schmidt & Clark 1995). Clark (1984) reported a comprehensive rock magnetic study of pyrrhotite, which was sorely needed for applications of rock magnetism to exploration. Many of the results of this laboratory are in CSIRO reports to commercial sponsors. The current focus of the laboratory is magnetic petrology, instrumentation such as differential vector magnetometry and, recently, expansion into applications to coal, petroleum and gas exploration. In 1987 Embleton became Chief of the Division, and the laboratory is currently run by Schmidt. The CSIRO laboratory has been, and is, intimately involved in training students from universities in Sydney, especially Macquarie University. In recent years, most Australian PhDs in palaeomagnetism and rock magnetism have graduated from Macquarie University, under co-supervision by CSIRO staff.

University of Western Australia laboratory

While at Macquarie University, Chris Powell became increasingly interested in palaeomagnetism throughout the 1980s and when he left Macquarie University to take up the chair of geology at the University of Western Australia in 1990, a new palaeomagnetic laboratory was spawned there, using renovated equipment from CSIRO. Zheng-Xiang Li, who gained his PhD from Macquarie University using CSIRO facilities, soon followed to take over the general running of the new laboratory. Since then the laboratory has acquired the latest equipment, including a top-of-the-line cryogenic magnetometer.

Most projects that the University of Western Australia laboratory is working on have to do with Precambrian problems, although the tectonics of South East Asia is also central to their interests. This laboratory has contributed a number of papers, including studies of the formation and breakup of Gondwanaland and Rodinia (Li & Powell 1993, Powell et al. 1993, Li et al. 1995), the supercontinent that begat Pangaea, Rodinia being Russian for 'to beget'. In addition, the laboratory has established itself in applied palaeomagnetism and has attracted industry funding to study banded iron formations and iron ore. This laboratory is the only active university-based laboratory in Australia today.

Concluding remarks

It is clear that Australian palaeomagnetic and rock magnetic research have played an important, and often leading, role in the early growth of these fields. The results from the first ANU laboratory, including those from the Tasmanian Dolerite, gave overwhelming evidence in favour of continental drift. Apart from the fact that about half the books on palaeomagnetism and rock magnetism have emanated from Australian laboratories, Australia's legacy to palaeomagnetic studies is ensured by the various databases.

Throughout the 1970s and early 1980s the momentum in palaeomagnetic research was maintained with AGSO taking over from ANU, and CSIRO taking the initiative of building a special laboratory. Over the past decade, however, these studies have waned somewhat. This is in stark contrast to the huge growth of palaeomagnetic laboratories elsewhere, particularly in the USA. The reasons for this are manifold.

After ANU's withdrawal, there were no universities with mainstream interests in either palaeomagnetism or rock magnetism. Initial productive collaboration between CSIRO and Macquarie University was slowly choked by CSIRO's increasing requirement to tackle applied problems. In fact, the two main laboratories remaining after ANU's exit were both government laboratories (CSIRO and AGSO) that do not have complete freedom to undertake curiosity driven research. Many studies are confidential to sponsors and their publication embargoed.

The new University of Western Australia laboratory should compensate somewhat for the decline in government pure-research, but universities are now actively competing with government laboratories for industry funding. Both government and industry should be alarmed at this situation. In the long term, the maintenance of a reasonable level of curiosity driven research is indispensable for the sustenance of applied research. This problem is not limited to rock magnetic and palaeomagnetic laboratories and is one of the great challenges facing science in Australia today.

Acknowledgments

It is with deep sorrow that as I finish this brief history of Australian palaeomagnetism/rock magnetism I have just heard of Keith Runcorn's tragic death. As David Stone said in a message circulated to AGU members, 'I am sure that we will all miss him greatly.'

I am indebted to Ted Irving for mentioning the Strzelecki account to me whilst I was a postdoctoral fellow at the Earth Physics Branch, Ottawa in 1978. The liberal interpretations of Strzelecki's observations, however, are purely the result of my artistic licence. Many colleagues suggested pertinent improvements and corrections to an earlier version of the paper, but undoubtedly omissions (hopefully not errors) and personal biases remain, for which I apologise.

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